LCA Case Studies

Life Cycle Inventory for Electricity Generation in China

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Abstract

Background, Goal and Scope. The objective of this study was to produce detailed a life cycle inventory (LCI) for the provision of 1 kWh of electricity to consumers in China in 2002 in order to identify areas of improvement in the industry. The system boundaries were processes in power stations, and the construction and operation of infrastructure were not included. The scope of this study was the consumption of fossil fuels and the emissions of air pollutants, water pollutants and solid wastes, which are listed as follows: (1) consumption of fossil fuels, including general fuels, such as raw coal, crude oil and natural gas, and the uranium used for nuclear power; (2) emissions of air pollutants from thermal power, hydropower and nuclear power plants; (3) emissions of water pollutants, including general water waste from fuel electric plants and radioactive waste fluid from nuclear power plants; (4) emissions of solid wastes, including fly ash and slag from thermal power plants and radioactive solid wastes from nuclear power plants.

Methods. Data were collected regarding the amount of fuel, properties of fuel and the technical parameters of the power plants. The emissions of CO_2, SO_2, NO_x, CH_4, CO, non-methane volatile organic compound (NMVOC), dust and heavy metals (As, Cd, Cr, Hg, Ni, Pb, V, Zn) from thermal power plants as well as fuel production and distribution were estimated. The emissions of CO_2 and CH_4 from hydropower plants and radioactive emissions from nuclear power plants were also investigated. Finally, the life cycle inventory for China's electricity industry was calculated and analyzed.

Results. Related to 1 kWh of usable electricity in China in 2002, the consumption of coal, oil, gas and enriched uranium were 4.57E-01, 8.88E-03, 7.95E-03 and 9.03E-08 kg; the emissions of CO_2, SO_2, NO_x, CO, CH_4, NMVOC, dust, As, Cd, Cr, Hg, Ni, Pb, V, and Zn were 8.77E-01, 8.04E-03, 5.23E-03, 1.25E-03, 2.65E-03, 3.95E-04, 1.63E-02, 1.62E-06, 1.03E-08, 1.37E-07, 7.11E-08, 2.03E-07, 1.42E-06, 2.33E-06, and 1.94E-06 kg; the emissions of waste water, COD, coal fly ash, and slag were 1.31, 6.02E-05, 8.34E-02, and 1.87E-02 kg; and the emissions of inactive gas, halogen and gasoloid, tritium, non-tritium, and radioactive solid waste were 3.74E+01 Bq, 1.61E-01 Bq, 4.22E+01 Bq, 4.06E-02 Bq, and 2.68E-10 m^3 respectively.

Conclusions. The comparison result between the LCI data of China's electricity industry and that of Japan showed that most emission intensities of China's electricity industry were higher than that of Japan except for NMVOC. Compared with emission intensities of the electricity industry in Japan, the emission intensities of CO_2 and Ni in China were about double; the emission intensities of NO_x, Cd, CO, Cr, Hg and SO_2 in China were more than 10 times that of Japan; and the emission intensities of CH_4, V, Pb, Zn, As and dust were more than 20 times. The reasons for such disparities were also analyzed.

Recommendations and Perspectives. To get better LCI for the electricity industry in China, it is important to estimate the life cycle emissions during fuel production and transportation for China. Another future improvement could be the development of LCIs for construction and operation of infrastructure such as factory buildings and dams. It would also be important to add the information about land use for hydropower.

Keywords: China; electricity industry; emission intensity; hydropower plant; life cycle inventory (LCI); nuclear power plant; thermal power plant

Introduction

Electricity is a major consideration in almost all of the life cycle assessment (LCA). It is important to accurately calculate and model resource use and pollutant releases for activities related to the generation and distribution of electricity, such as how and where electricity is produced, with what input requirements and with what pollution and waste consequences. The benefits of public life cycle inventory (LCI) data on electricity generation would be high for those who undertake LCA and for those who draw conclusions based on LCA. Therefore, the LCI studies for power production were carried out in many countries [1–6].

There is, however, the problem that only a few figures [7–14] concerning emissions related to China's electricity industry have been reported. One solution is to develop process models for power plants that simulate the mass flows and estimate the missing figures of emissions dependent on technical parameters of the plants and fuels. In this work, process models of power plants were developed based on the Chinese situation, and the data concerning technical parameters of the plants and fuels were also collected. The results, data, methods, assumptions and limitations were transparent and presented in sufficient detail to allow readers to comprehend the complexities and trade-offs inherent in the LCA study.

1 Introduction to China's Electricity Industry

China is the second largest power production and consumption country in the world. By the end of 2002, the total national installed capacity had reached 356.6 GW with a yearly electricity generation of 1654.2 TWh [15]. Up to now, the electricity grid system of China has been mainly constituted by 5 trans-regional grids (North China, Northeast China, East China, Central China and Northwest China), South China Electric Power Joint-venture Network and 7 independent provincial or municipal networks. Trans-province grids and Shandong Grid have built 500 kV or 330 kV transmission lines as main trunks, while East China and Central China grids have been inter-connected through 500 kV DC transmission lines. The networks above cover most parts of rural and urban areas in China, providing qualified, reliable electricity and supply services.

Thermal power has been the principal part of total national installed capacity and electricity generation in China. Development of hydropower is slower than that of thermal power, and nuclear power is just in its initial step. New energy resources power generation, such as wind, solar energy and tide, is not included in this paper due to the small share of yearly electricity generation.

2 Goal, Scope and Background

The goal of this study was to develop LCI for the China's electricity industry in 2002. The functional unit was 1 kWh of electricity distributed to users in China, which was regarded as 1 kWh of net electricity production.

The scope of this study was the consumption of fossil fuels and the emissions of air pollutants, water pollutants and solid wastes, which were listed as follows: (1) consumption of fossil fuels, including the general fuels, such as raw coal, crude oil and natural gas, and the uranium used for nuclear power; (2) emissions of air pollutants, including CO_2, SO_2, NO_x, CH_4, CO, non-methane volatile organic compound (NMVOC), dust (all particulates), heavy metals (Ni, V, As, Cd, Cr, Hg, Pb, Zn) and radiation and radioactive emissions from atomic power stations; (3) emissions of water pollutants, including general water waste from fuel electric plants and radioactive waste fluid such as tritium and non-tritium species from nuclear power plants; (4) emissions of solid wastes, including fly ash and slag from thermal power plants and radioactive solid wastes from nuclear power plants.

System boundaries of this study were processes in power stations, i.e. fuel combustion, pollution abatement technologies, electric power distribution and life cycle processes related to fuels. For thermal power plants, mining and transportation of raw coal, crude oil and natural gas were included; for nuclear power plants, mining, processing and transportation of uranium mineral were included.

3 LCI of Thermal Power Plants

In this section, the direct emissions from fuels consumption of thermal power plants in China were first calculated, and then, the LCI of thermal power plants would be got based on the related references of fuel production and their transportation.

3.1 Fossil energy consumption

According to China Energy Statistical Yearbook [16], the consumption of coal, oil and gas of thermal power plants in 2002 was 6.56E+08 t, 1.27E+07 t and 1.14E+10 m^3 respectively. Many grades of fuels are being used to produce power in China. In general, coal consists of raw coal, cleaned coal and other washed coal, oil consists of crude oil, diesel oil, and fuel oil, and gas consists of natural gas, coke oven gas and other gas. However, it is rather difficult to get the reliable equations and factors to estimate the related emissions for these specific fuels. So some simplification is accepted in the article. The coal is studied as raw coal, the oil crude oil, and the gas natural gas. For the dominant proportion of raw coal in the national fuel consumption by thermal power plants, the deviation of the results could be accepted.

3.2 Air pollutants

(1) CO_2

After the burning of fuels, most carbon is released as CO_2, some is released as CO, and the rest is retained in the ashes and slag. The carbon emission coefficient (kg-C/MJ), i.e. potential amount of carbon emission for the fuel, depends highly on the heat capacity of carbon in the fuel. Carbon oxidation coefficient is another indicator for CO_2 emission characteristics of fuel. In fact, it is also related to the combustion equipment, technology and operation conditions. CO_2 emissions for fuels burning in thermal power plants were calculated by **Eq. (1)**:

$$E = 3.67FQk\alpha \quad (1)$$

where

E: CO_2 emissions (kg-CO_2);
F: amount of fuel consumption (kg or m^3);
Q: calorific values of fuels (MJ/kg or MJ/m^3);
k: carbon emission coefficient for fuels (kg-C/MJ); and
α: carbon oxidation coefficient.

Wu et al. [17] determined carbon emission coefficient for raw coal, which was 5% less than default value recommended by IPCC [18]. And the coefficients for crude oil and natural gas were default value recommended by IPCC. Carbon oxidation coefficients listed in **Table 1** were calculated by a carbon equilibrium analysis of combustion devices such as industrial boilers, railway steam engines as well as devices used in steel and chemical industries in China.

(2) SO_2

Sulfur is one of the common harmful elements in coal. There are three existing forms of sulfur in raw coal: sulphate, pyrites and organic sulfur. Sulphate is incombustible, while pyrites and organic sulfur are combustible. SO_2 emissions

Table 1: Carbon emission coefficients and carbon oxidation coefficients

Fuels	Raw coal	Crude oil	Natural gas
Carbon emission coefficient, (kg-C/MJ)	0.0247	0.0200	0.0153
Carbon oxidation coefficient, (–)	0.90	0.98	0.99

could be calculated accurately by combustible sulfur content in coal and ash after combustion. In this work, because the goal was to obtain national SO_2 emissions and there were no sufficient data for all the thermal power plants, SO_2 emissions from coal burning were extrapolated from coal quality checking data. Moreover, as desulphurization technologies could reduce SO_2 emissions effectively, the emissions are also related to the cover rate of power generation units equipped with desulfurizers and their desulfurization efficiency. Similarly, SO_2 emissions of crude oil and natural gas were estimated based on their sulfur contents, SO_2 emission factors and the desulfurization of power plants. Therefore, SO_2 emissions of thermal power plants were calculated by **Eq. (2)**:

$$E = 2FS\alpha(1 - rf) \quad (2)$$

where

E: SO_2 emissions (kg-SO_2);
F: amount of fuel consumption (kg or m^3);
S: total sulfur content of fuels consumed (wt% or kg/m^3);
α: emission rate for certain fuel;
r: cover rate of generator sets equipped with desulfurizers; and
f: average desulfurization efficiency.

According to related researches [19,20], the sulfur content of raw coal was 1.05%, the sulfur content of oil 0.12% [21], and the sulfur content of natural gas 0.13 g/m^3 [22]. SO_2 emission factor for raw coal and crude oil was 81% and 93% [23,24] respectively in this work, and the factor for natural gas was 100% because there is usually little ash remaining after combustion.

According to China Electricity Yearbook 2003 [15], there were about 5000 MW of generator sets equipped with desulfurizers in China, which account for about 2% of the thermal power plants with installed capacity. According to the main types of desulfurizers and their desulfurization efficiency, average desulfurization efficiency of thermal power plants in China was 90%.

(3) NO_x

NO_x emissions from fossil fuel power stations consist of fuel NO_x and thermal NO_x. NO_x emissions from fossil fuel power stations depend on the nitrogen content of fuels, the temperature inside the boilers in power stations, and the cover ratio of denitrification facilities in power stations and their efficiencies.

Since data concerning the nitrogen content of fuels and temperature inside the boilers in power stations were not available, the **Eq. (3)** was adopted:

$$E = F\alpha(1 - rf) \quad (3)$$

where

E: NO_x emissions (kg-NO_x);
F: amount of fuel consumption (kg or m^3);
α: NO_x emission factor for certain fuel;
r: cover rate of generator sets equipped with denitrators; and
f: average denitrification efficiency.

The emission factors for fuels were obtained from the literature [25]. The factors for raw coal, crude oil and natural gas were revised by an air pollution survey of China's thermal power stations, and were 12.20 kg/t, 17.20 kg/t and 3.74 kg/t respectively.

There is almost no control on NO_x emissions from fossil fuel power stations in China. Denitrification wasn't included in this work because there were just a few power stations equipped with denitrification facilities in China.

(4) CO, CH_4 and NMVOC

Based on the amount of fuel, heat capacity and emission factors, CO, CH_4 and NMVOC emissions were calculated by **Eq. (4)**:

$$E_i = FQ\alpha_i \quad (4)$$

where

E: emissions of gas i (kg-i);
F_i: amount of fuel consumption (kg or m^3);
Q: heat capacity of certain fuel (MJ/kg or MJ/m^3); and
α_i: emission factor for gas i (kg/MJ).

Emission factors for CO and CH_4 emissions were the default value recommended by IPCC, and that of NMVOC was obtained from Ref. [26]. They are listed in **Table 2**.

Table 2: Emission factors for CO, CH_4 and NMVOC in thermal power plants (kg/TJ)

Power plant	CO	CH_4	NMVOC
Coal fired power plant	106	0.8	25
Oil fired power plant	350	4	2
Natural gas fired power plant	46	6	4

(5) Dust (all particulates)

Dust from burning fossil fuels consists of black smoke and fly ash. Precipitators are equipped in most coal-fired power stations in China to reduce dust emissions. Some stations are also equipped with desulfurizers, which would reduce dust emissions further.

Dust emissions from coal-fired boilers were calculated by **Eq. (5)**. Dust emissions of oil-fired and gas-fired ones are usually negligible.

$$E = F\alpha\left(\frac{A}{100} + \frac{Qq}{4.18 \times 8100 \times 100}\right)(1 - c\eta)(1 - rf_d) \quad (5)$$

where

E: dust emissions (kg-dust);
F: amount of fuel consumption (kg or m^3);
α: the ratio of ash in dust to the total ash in the fuel;
A: the monitoring ash content of fuel (% or g/m3);
Q: the heat capacity of certain fuel (MJ/kg or MJ/m^3);
q: the heat loss of mechanically incomplete combustion (%);
c: cover rate of generator sets equipped with precipitators;
η: average precipitating efficiency of precipitators;
r: cover rate of generator sets equipped with denitrators; and
f_d: average precipitating efficiency of desulfurizers.

From Wang [27], average ash content in the coal of China was about 26%. Concerning several types of the coal-fired boilers in common use [28], the average heat loss of mechanically incomplete combustion, 10%, was used. The average ratio of ash in dust to the total ash was 50%. The cover rate of coal-fired power generation units equipped with precipitators was about 80%, and the efficiency of precipitators in coal-fired power stations was 97% [29]. The reduction rate of dust emissions by a desulfurizer was assumed to be 90% according to reference [30].

(6) Heavy metal elements

Heavy metal elements (Ni, V, As, Cd, Cr, Hg, Pb, and Zn) emission from coal-fired power stations and oil-fired power stations was investigated in this work. Heavy metal elements emission from gas-fired power stations was not considered due to the lack of information.

In the process of fuels combustion, some heavy metal elements in fuels would be transferred into ash, and the rest would be released into exhaust gas from boilers. Electrostatic precipitators and desulfurizers would trap some of the heavy metals in exhaust gas, and the rest of the heavy metals would be emitted into the air. Therefore, heavy metal element emission from power stations could be calculated according to the heavy metal content in fuel, fuel consumption, ratio of gasified heavy metal to its total content, and the trap ratio of heavy metal by precipitators, as expressed in **Eq. (6)**:

$$E_i = Fm_i\alpha_i\ (1 - c\eta_i)(1 - rf_i) \quad (6)$$

where
E: emissions of heavy metal i (kg-i);
F_i: amount of fuel consumption (kg or m^3);
m_i: heavy metal i content of fuels(wt% or g/m^3);
α_i: gasification conversion rate of heavy metal i;
c: cover rate of generator sets equipped with precipitators;
η_i: trap ratio of heavy metal i by precipitators;
r: cover rate of generator sets equipped with denitrators; and
f_i: trap ratio of heavy metal i by desulfurizers.

The content of As, Cd, Cr, Ni, Pb, V and Zn in the raw coal of China were 4.26, 0.32, 17.97, 15.22, 19.69, 37.66, and 28.90 mg/kg [31], and the content of As, Cd, Cr, Ni, Pb, V and Zn in crude oil were 233.35, 0.016, 0.067, 11.60, 0.009, 0.49, and 4.81 mg/kg [32]. The content of Hg in raw coal and crude oil was 0.22 mg/kg [33] and 0.59 ¼g/kg [34] respectively.

According to references [35–37], the gasification conversion rate of As, Cd, Cr, Ni, Pb and Zn during coal combustion is 65%, 15%, 8%, 12%, 74% and 68% respectively. As the gasification conversion rate of Hg was usually 64.0%~78.2% [38], the average value, 71.1%, was assumed here. The gasification conversion rate of V during coal combustion and oil combustion is 65% and 90% respectively [39]. Because there are few references on gasification conversion rate of heavy metals during oil combustion, the parameters of coal combustion were used in the work.

The trap ratios of heavy metals by precipitators and desulfurizers in coal-fired and oil-fired power plants [30] are listed in **Table 3**.

(7) Direct air pollutants emissions from thermal power stations in China

As above, the direct air pollutants emissions from thermal power stations in China in 2002 were estimated and listed in **Table 4**.

Table 3: Heavy metals trap ratios by precipitators and desulfurizers in coal-fired and oil-fired power plants

	As	Cd	Cr	Hg	Ni	Pb	V	Zn
Desulfurizer	75	75	85	60	85	75	85	75
Precipitator (coal-fired)	98	97	99	0	99	98	99	98
Precipitator (oil-fired)	–	–	–	–	60	–	60	–

Table 4: Air emissions of fuel power generation station

Emissions	CO_2	SO_2	NO_x	CO	CH_4	NMVOC	Dust	
Coal	1.12E+09	1.10E+07	8.00E+06	1.46E+06	1.08E+04	3.43E+05	2.32E+07	
Crude oil	3.83E+07	2.80E+04	2.19E+05	1.87E+05	2.13E+03	1.07E+03	0	
Natural gas	2.47E+07	2.91E+03	3.06E+04	2.04E+04	2.67E+03	1.78E+03	0	
Total	1.18E+09	1.10E+07	8.25E+06	1.66E+06	1.56E+04	3.46E+05	2.32E+07	
Emissions	**As**	**Cd**	**Cr**	**Hg**	**Ni**	**Pb**	**V**	**Zn**
Coal	3.86E+02	6.95E+00	1.93E+02	1.01E+02	2.45E+02	2.03E+03	3.28E+03	2.74E+03
Crude oil	1.93E+03	3.06E-02	6.84E-02	5.34E-03	1.78E+01	8.50E-02	5.63E+00	4.17E+01
Natural gas	0	0	0	0	0	0	0	0
Total	2.32E+03	6.98E+00	1.93E+02	1.01E+02	2.63E+02	2.03E+03	3.29E+03	2.78E+03

Table 5: Air emissions during fuels production and transportation

Emissions		CO_2 (kg)	SO_2 (kg)	NO_x (kg)	CO (kg)	CH_4 (kg)	NMVOC (kg)	Dust (kg)	
Coal	1 kg	7.73E-02	7.36E-04	1.22E-03	1.96E-04	4.45E-03	1.88E-04	3.24E-04	
Oil	1 kg	2.73E-01	9.63E-04	2.05E-03	7.00E-03	2.54E-03	4.83E-04	1.32E-04	
LNG	1 kg	6.61E-01	9.26E-04	1.29E-03	3.23E-04	6.71E-03	4.91E-04	3.01E-05	
Enriched uranium	For 1 kWh	7.17E-02	3.08E-04	3.10E-04	1.48E-05	8.65E-05	2.29E-05	3.17E-05	
Emissions		**As**	**Cd**	**Cr**	**Hg**	**Ni**	**Pb**	**V**	**Zn**
Coal	1 kg	3.35E-09	1.09E-09	4.66E-09	9.94E-10	3.92E-08	1.18E-08	7.35E-08	9.71E-09
Oil	1 kg	3.27E-09	8.28E-09	4.12E-09	8.18E-10	1.63E-07	1.44E-08	6.50E-07	1.03E-08
LNG	1 kg	4.29E-09	1.09E-08	5.32E-09	1.59E-08	2.14E-07	1.89E-08	8.56E-07	1.33E-08
Enriched uranium	For 1 kWh	1.27E-08	8.60E-10	1.86E-08	4.36E-09	4.05E-08	4.51E-08	2.18E-08	3.72E-08

3.3 Water pollutants and solid wastes

Because the emissions of industrial waste water and solid wastes are important parts of environmental statistics documents by the State Environmental Protection Administration of China, the related data were obtained from official statistics. According to the China Environmental Yearbook 2003 [40], the industrial wastewater discharged by thermal power plants in China in 2002 was 1.89E+09 t, in which the COD discharged was 8.64E+04 t. The coal fly ash and slag dumped was 1.20E+08 t and 2.68E+07 t respectively.

3.4 Emissions during fuel production and transportation

Because of a lack of LCI data about emissions during fuels production and transportation in China, the research results of Japanese authors [30] were adopted in this study, which is listed in **Table 5**.

Table 6: Life cycle emissions of thermal power plants in China in 2002 (t)

Pollutant	Emission
CO_2	1.24E+09
SO_2	1.15E+07
NO_x	9.09E+06
CO	1.80E+06
CH_4	3.02E+06
NMVOC	5.66E+05
Dust	2.34E+07
As	2.33E+03
Cd	1.48E+01
Cr	1.96E+02
Hg	1.02E+02
Ni	2.91E+02
Pb	2.04E+03
V	3.35E+03
Zn	2.79E+03
Industrial water	1.89E+09
COD	8.64E+04
Coal fly ash	1.20E+08
Slag	2.68E+07

3.5 Life cycle emissions of thermal power plants in China

As above, the life cycle emissions of thermal power plants in China were obtained, and are listed in **Table 6**. It should be noted here that because water pollutants and solid waste during fuel production and transportation were not included in this work due to the lack of data, some deviation in the results would be included.

4 Life Cycle Emissions of Hydropower Plants and Nuclear Power Plants

Greenhouse gas (CO_2 and CH_4) emissions at reservoirs were the main portion of environmental emissions of hydropower stations when environmental effects of infrastructure construction were not included. The emissions were the product of greenhouse gas emission flux and the area of the reservoirs. According to Ma [41], average greenhouse gas emission flux for CO_2 and CH_4 yearly caused by reservoirs was 3.11E+02 g/m^2 and 1.58E+01 g/m^2 respectively, and the normalized water area of increased drowned land by large & medium hydropower plants and small hydropower plants was 4.95E+01 m^2/kW and 7.14E+02 m^2/kW respectively. Based on installed capacities of hydropower plants above 25MW and below 25 MW, the CO_2 and CH_4 emissions of hydropower plants in China in 2002 were 1.53E+07 t and 7.75E+05 t respectively. For estimating the impacts of hydropower, land use is usually important to consider. However, because land use is not so mature as other impact categories such as abiotic resource depletion, climate change and acidification, it was not discussed in the study.

Radiological impacts can be one of the most important environmental effectss of nuclear power plants. Nuclear power plants usually have 3 types of radioactive waste: liquid radioactive waste, gaseous radioactive waste and solid radioactive waste. Nuclear pollutant emissions from nuclear power plants in China in 2002 were extrapolated by the Daya Bay Nuclear Power Plant in 1999 due to the limitation of available data. Original data [42] and the estimated results are listed in **Table 7**.

5 Results and Discussion

As above, the LCI for 1 kWh of electricity generation in China is calculated and listed in **Table 8**. The transmission of electricity in all cases is taken to be distributed from the power

Table 7: Life cycle inventory of nuclear power of China

	Fuel consumption	Radioactive gas		Radioactive liquid		RSW
	EU (t)	Inactive gas (TBq)	H&G (MBq)	Tritium 8 (TBq)	Non-tritium (MBq)	m^3
Daya Bay Nuclear Power Plant	70.00	25.8	111.2	29.1	28.0	184.6
Nuclear power industy of China	129.67	53.8	231.7	60.6	58.3	384.6

EU: enriched uranium; H&G: Halogen and gasoloid; RSW: Radioactive solid waste

Table 8: LCI for Electricity Generation in China in 2002

	Fuel consumption				Air pollutants		
	Coal-fired	Oil-fired	Gas-fired	EU	CO_2	SO_2	NO_x
	kg/kWh	kg/kWh	m^3/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh
Per 1kWh	3.97E-01	7.71E-03	6.90E-03	7.84E-08	7.61E-01	6.98E-03	5.50E-03
Per net 1kWh	4.57E-01	8.88E-03	7.95E-03	9.03E-08	8.77E-01	8.04E-03	6.34E-03
	Air pollutants						
	CO	CH_4	NMVOC	Dust	As	Cd	Cr
	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh
Per 1kWh	1.09E-03	2.30E-03	3.43E-04	1.42E-02	1.41E-06	8.94E-09	1.19E-07
Per net 1kWh	1.25E-03	2.65E-03	3.95E-04	1.63E-02	1.62E-06	1.03E-08	1.37E-07
	Air pollutants					Water emissions	
	Hg	Ni	Pb	V	Zn	Waste water	COD
	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh	kg/kWh
Per 1kWh	6.17E-08	1.76E-07	1.24E-06	2.02E-06	1.69E-06	1.14E+00	5.23E-05
Per net 1kWh	7.11E-08	2.03E-07	1.42E-06	2.33E-06	1.94E-06	1.31E+00	6.02E-05
	Solid wastes		Radioactive air		Radioactive water		RSW
	Fly ash	Slag	Inactive gas	H&G	Tritium	Non-tritium	
	kg/kWh	kg/kWh	Bq/kWh	Bq/kWh	Bq/kWh	Bq/kWh	m^3/kg
Per 1kWh	7.24E-02	1.62E-02	3.25E+01	1.40E-01	3.67E+01	3.53E-02	2.33E-10
Per net 1kWh	8.34E-02	1.87E-02	3.74E+01	1.61E-01	4.22E+01	4.06E-02	2.68E-10

EU: enriched uranium; H&G: Halogen and gasoloid; RSW: Radioactive solid waste

station via a high voltage electricity grid to low voltage electricity suitable for domestic use, causing a loss of 7.52% of the electricity produced at the power station. And a loss of 6.15% was caused by the electricity consumption at the power plants [15]. The LCI for 1 kWh of electricity distributed to end users in China is also calculated and listed in Table 8.

In order to provide a deep understanding for the status of the environmental aspects of the China's electricity industry, this paper compared some major indices with those of the advanced world standard. Due to the limitation of available environmental references, the data of Japan's electricity grid mixes in 1997 [30] were selected.

Copared with emissions related to 1 kWh of electricity distributed by the Japan's electricity industry, the relative values of emissions related to 1 kWh of electricity distributed by the China's electricity industry were calculated, as shown in **Fig. 1**. The emissions analyzed included CO_2, SO_2, NO_x, CO, CH_4, NMVOC, dust, As, Cd, Cr, Hg, Ni, Pb, V and Zn.

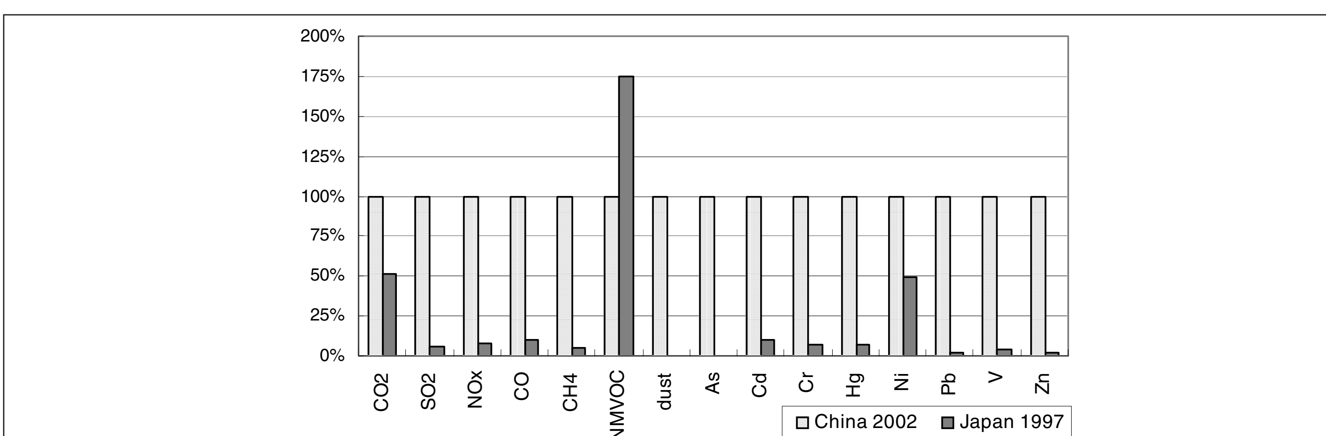

Fig.1: Comparison of emissions related to 1kWh of electricity distributed between China and Japan

As shown in Fig. 1, all the emissions related to 1 kWh of electricity distributed by the electricity industry of China were more than those of Japan except NMVOC, in which, the emission intensities of CO_2 and Ni in Japan were about half of the emission intensities of CO_2 and Ni in China. The emission intensities of SO_2, Hg, Cr, NO_x, CO and were Cd as low as 10% of the corresponding emission intensities of China, and the emission intensities of others, including dust, As, Zn, Pb, V and CH_4 were not more than 5% of the corresponding parameters of China. The comparison showed that the control of pollutants from power plants in China was much lower than the international level. The reasons were as follows:

(1) Compared with developed countries, such as U.S., Russia, Japan and France, the contribution of thermal power was obviously higher in the electric power structure of China. And general emission intensities from thermal electric plants were much more than that of hydropower plants or nuclear power plants.

(2) Coal fired power generation was chiefly used in China's thermal power. During the 1990's, the proportion was more than 90%. But the proportion of coal fired power generation of Japan's electricity industry was only 30%, and of oil-fired and gas-fired was 1/3 and 1/3 respectively. Compared with oil fired and gas fired power plants, emission intensities of coal fired power plants were much higher.

(3) The technologies of China's electric power generation and distribution are still backward. The standard coal consumption related to 1 kWh of electricity distributed by Japan's electricity industry in 1997 was 324 g/kWh, while that of China's in 2002 was 383 g/kWh and was 18.2% higher. The reason was lower fuel usage efficiency and higher distribution loss of China's electricity industry.

(4) The treatment of stack gases in China's thermal power plants was much lower than the international level. The cover rate of generator sets equipped with denitrators was 80%, and the average precipitating efficiency of precipitators was about 97% in 2002, while most generator sets were equipped with denitrators in Japan and the average precipitating efficiency of precipitators was as high as 99.5%. The cover rate of generator sets equipped with desulfurizers in China was less than 2%, and the denitrification was just in the initial stage in China's thermal power plants.

6 Conclusions, Recommendations and Perspectives

Process models of power plants were developed for the China's situation on paper. Life cycle inventories (LCI) for the electricity industry in China were developed. The functional unit was 1 kWh of electricity distributed to electricity users. The emissions of CO_2, SO_2, NO_x, CH_4, CO, non-methane volatile organic compound (NMVOC), dust (all particulates) and heavy metals (Ni, V, As, Cd, Cr, Hg, Pb, Zn) from thermal power plants as well as those from fuel production and distribution were investigated. The emissions of CO_2 and CH_4 from hydropower plants and radioactive emissions from nuclear power plants were also calculated. The LCI is fundamental for related LCI and LCA in China for the special role of electricity in modern industry. The LCI showed that the control of pollutants from power plants in China was much lower than the international level. The emission intensities of CO_2 and Ni of the electricity industry in China was more than double the emission intensities of CO_2 and Ni in Japan; the emission intensities of Cd, CO, NO_x, Cr, Hg and SO_2 in China were more than 10 times the corresponding emission intensities in Japan; and the emission intensities of CH_4, V, Pb, Zn, As and dust were more than 20 times those of Japan. The main reasons for the disparity were also analyzed.

This work will promote the development of LCI and/or LCA research and application in China. The method and process models studied in this paper are suitable for the electricity industry as well as other industries. In addition, since the power production sector is being subjected to increasingly stringent environmental regulations, establishing environmental loads data for power production is important for the identification and improvement of its environmental aspects.

To get better LCI for the electricity industry in China, it is important to estimate the life cycle emissions during fuel production and distribution for China. Another future improvement could be the development of LCIs for construction and operation of infrastructure such as factory buildings and dams. For estimating the impacts of hydropower, land use is usually an important consideration. Though land use wasn't discussed in the study because its environmental impact is a relatively new topic in life cycle impact assessment and still being debated and developed, it will be necessary to add land use information to the future work.

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